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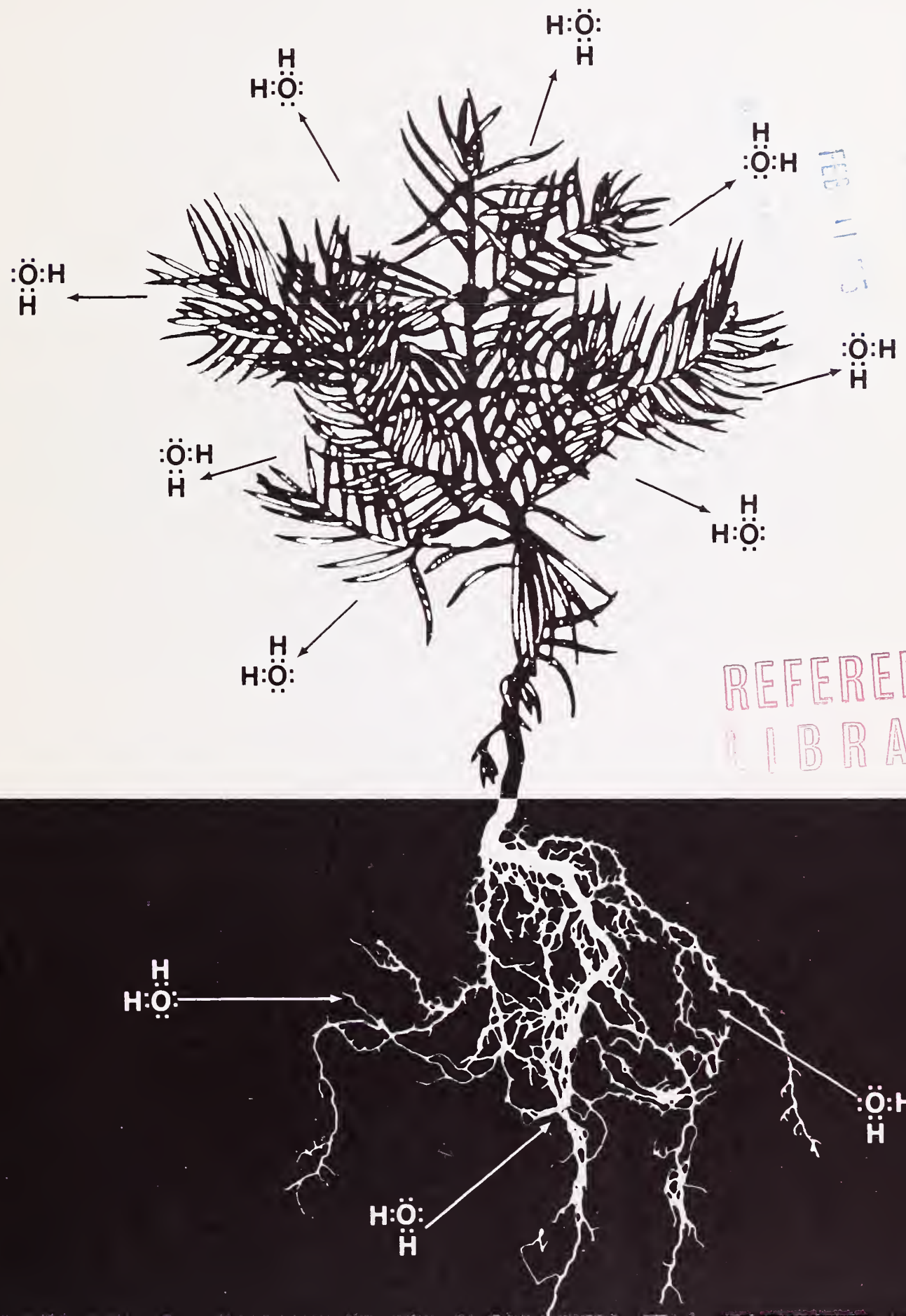
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Moisture Stresses in Arizona Mixed Conifer Seedlings

by
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ABSTRACT

Dry-season moisture stresses were measured in wild seedlings of Douglas-fir, ponderosa pine, Engelmann spruce, and corkbark fir. Seedlings less than about 15 cm (6 inches) tall had higher stresses than larger trees; above 15 cm size made no difference. Nighttime recovery was complete. There was no increasing trend of stresses through the dry season on sites and seedling sizes sampled, and day-to-day variability seemed a function of day-to-day weather differences. Species differences were small but significant. There are implications for planting and for the use of plant moisture stress measurements in classifying regeneration habitats.

Keywords: Habitat classification, seedling survival, seedling growth, regeneration, Pseudotsuga menziesii var. glauca, Pinus ponderosa, Picea engelmannii, Abies lasiocarpa var. arizonica, pressure bomb.

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by

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Contents

	Page
Literature Review	1
Factors Affecting Stress	1
Effects on Trees	2
Moisture Environment of the Study Area.....	2
Methods.....	3
Results	3
Seedling Size.....	3
Effects of Variability on Sampling	4
Sunny vs Shady Side.....	4
Species Differences.....	4
Diurnal Stress Changes	4
Changes During the Season.....	6
Effects of Grass and Elevation.....	6
Discussion	7
Survival.....	7
Function and Growth	7
Habitat Classification	7
Primary Management Significance.....	8
Literature Cited.....	8

Moisture Stresses in Arizona Mixed Conifer Seedlings

John R. Jones

Because much of the Southwest is arid or semiarid, some foresters feel that drying is the most critical source of regeneration failures in the region. But the Southwest has large climatic differences; those familiar with southwestern mixed conifer forests know how wet they often are. They also know the persistent dry and often windy weather that characterizes these mixed conifer forests in spring and early summer.

In this study, seedling moisture stresses were examined during the dry season in Arizona mixed conifer forest. The possibility of using plant moisture stress (PMS) was also explored as a tool in classifying regeneration habitats on the basis of physiographic factors or vegetation types.

Literature Review

Moisture stress measurements have been variously reported in atmospheres (atm) and bars. Bars are used here. Where atm were used in the literature reviewed, they have been converted here to bars (1 atm equals 1.013 bars).

Factors Affecting Stress

Any factors that influence vapor pressure deficits (VPD) in and adjacent to leaves should affect PMS; so should factors that influence moisture movement into and through plants. Thus Pierpoint (1967) found higher stresses on the exposed sides of pole-sized red pine (*Pinus resinosa*) than on the shady sides. When soils are not too dry, low nocturnal VPD result in low PMS. Stresses rise after sunup in response to rising VPD. When soils are dry enough, moisture uptake is slowed sufficiently that daytime stresses become severe and nighttime recovery is incomplete.

In Oregon, Waring and Cleary (1967) found that with adequate soil moisture, PMS in Douglas-fir (*Pseudotsuga menziesii*) neared its peak before 1000 hr., climbed slightly and irregularly until 1430, then dropped sharply, approaching their minimum by 2000.

Cleary (1969) also showed the increases of PMS as the Oregon dry season progressed. Stresses stayed low for a time, then climbed in a sigmoid curve. As early as the end of June there was little nighttime recovery on a very coarse granitic soil. In a fine-textured soil there was considerable recovery at night as late as August, although dawn minima in July and August exceeded 30 bars.

Stresses in plants are considerably higher than in the soils they grow on. Pierpoint (1967) found that pole-sized red pine on a soil "near field capacity" had stresses averaging 9.7 bars on a cool, still, hazy day. On a bright day, trees growing on soils near field capacity can have stresses of 20 bars (Waring and Cleary 1967). The soil moisture stress at field capacity is 0.3 bar.

Waring and Cleary also pointed out that when trees 1 m tall had stresses nearing 40 bars, 25-m trees had stresses of 20 bars, presumably because the larger trees tap deeper soil layers where there is more water.

Effects on Trees

Judging from the literature as a whole, well-hydrated trees have stresses below 8 bars.

Waring and Cleary (1967) reported that different coniferous species in Oregon had similar PMS when growing together, but that the stresses they could survive seemed to be different. Other studies also indicate that lethal stress levels vary among coniferous species (Pierpoint 1967, Kaufmann 1968, Cleary 1969).

Data in Cleary (1969) suggest, but do not establish, that duration of high stresses may be important.

Moisture stresses far short of lethal have strong effects on growth and may influence survival indirectly. Brix (1962) found that photosynthesis in loblolly pine seedlings (*Pinus taeda*) began to decrease at a PMS of only 4 bars, and stopped at 11 bars. Respiration began to decrease at 7 bars.

Seedling growth rates of several coniferous species decreased sharply with small soil moisture deficits (Jarvis and Jarvis 1963, Stransky and Wilson 1964). Height growth of potted

shortleaf (*Pinus echinata*) and loblolly pines stopped entirely when soil moisture stresses (SMS) increased to only 3.5 bars. In contrast, Glerum and Pierpoint (1968) found seedling height growth of several Canadian conifers not seriously reduced by SMS as high as 15 bars. They suggested that the seeming incompatibility of their results with others may have been due to the brevity of their stress periods, and also pointed out the importance of timing relative to the period of maximum elongation.

Unfortunately, SMS can be translated into PMS only very loosely. Plant moisture stresses not only have a much greater daily range and sensitivity to transient atmospheric conditions; they also vary on different soils having the same soil moisture stress (Knipling and Miller 1965).

Moisture Environment of the Study Area

The study area is in the White Mountains of eastern Arizona. Elevations range from 2,700 to 2,800 m (8,900-9,200 feet). May and June have low relative humidities, abundant sun-

shine, much wind, and very little rain. Rains usually become frequent before mid-July, and sometimes in late June. The rest of the summer has abundant cloudiness. Measurable rain falls on about 50 percent of July and August days, and usually there are not more than a few consecutive days without measurable rain.

The moisture regime is characterized in figure 1. The diagram assumes a soil moisture retention capacity of 100 mm (4 inches)—appropriate for the rooting zone of well-developed seedlings in the gravelly silty loam soils predominant in the area. It also assumes a complete grass cover. Perhaps the most striking feature of the climate is the surplus of rain over potential evapotranspiration during July and August, partly the result of temperatures that rarely reach 27° C (80° F) and frequently stay below 21° C (70° F) throughout the day.

The 1970 dry season was near normal. On March 30, though south slopes were mostly bare, the general snowpack contained 7.8 inches of water, close to the 1964-71 average of 8.9 inches for that date. After 14 mm (0.54 inch) of water fell on April 17 and 18, only 16.5 mm (0.65 inch) more fell until June 23. Significant scattered showers began on June 23 and became frequent on July 1.

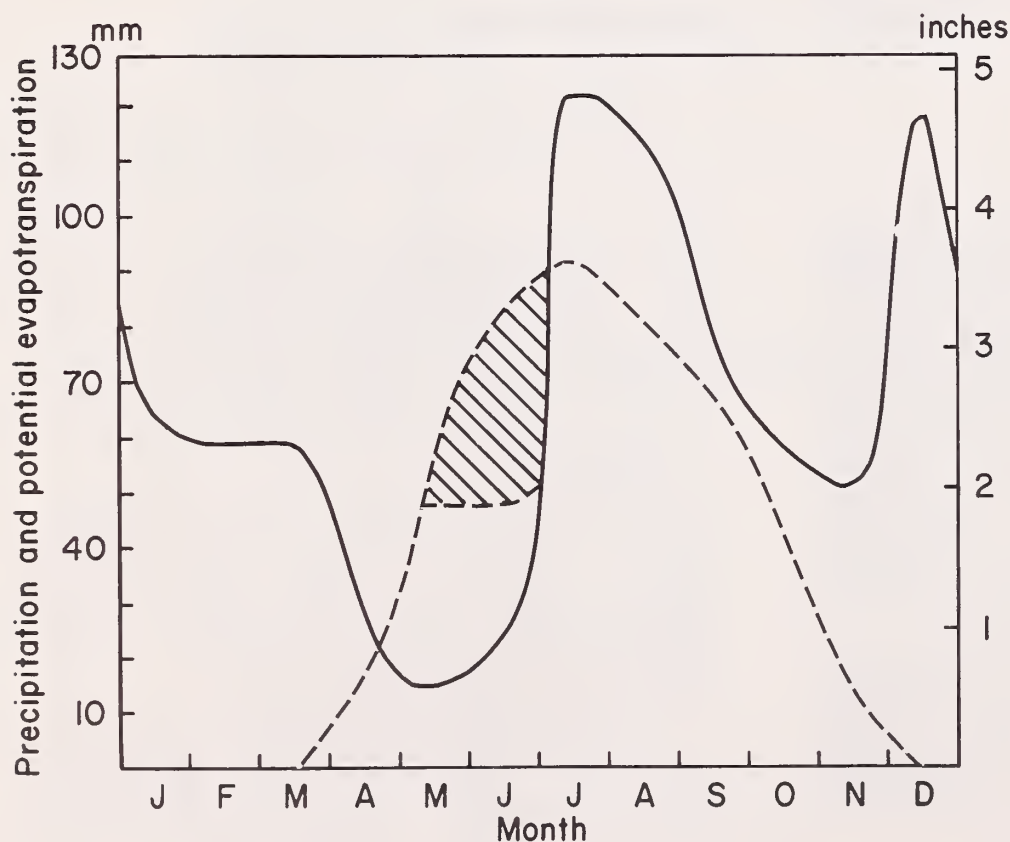


Figure 1.—Moisture regime. Solid line indicates precipitation, broken line potential evapotranspiration (PE). Hatched area indicates moisture deficit; its depth below broken line, amount of deficit (after Thornthwaite and Mather, 1957).

In the same locale, soil moisture was studied under grass and bare surfaces on clearcut northerly, level, and southerly slopes (Embry 1971). Below the surface inch or two, SMS reached or approached the permanent wilting point (15 bars) only on level and southerly sloping grassy plots. Under bare surfaces and on grassy north slopes no stresses were measured higher than 2.5 bars.

Methods

Stresses were measured with a portable pressure chamber. Measuring procedures were essentially those described by Waring and Cleary (1967). Daytime stresses in open-grown trees were from twigs exposed to the sun, unless otherwise specified. Also unless otherwise specified, stresses in trees not in the open were measured in shaded twigs, because in many trees all twigs were shaded and this practice reduced variation within an experiment. Hours are given in standard time.

A number of simple experiments were made to explore a number of relationships. Instead of describing the different methods here, they will be described briefly in connection with the results.

Results

Measured stresses did not approach those which the literature indicates are critical. Nor was there any sign of failure to recover fully at night. The highest midday stress measured was 22 bars in an Engelmann spruce (*Picea engelmannii*) that had had a dawn stress of only 5.3 bars. Nighttime recovery often brought individual stresses below 5.5 bars and occasionally to 4 bars.

Seedling Size

On May 20 and June 9, stresses measured in Engelmann spruce from 13 cm (5 inches) to 12 m tall were unrelated to height.

On June 17, stresses were measured in corkbark fir (*Abies lasiocarpa* var. *arizonica*) in a selectively cut stand, with the sample concentrated in the smaller seedling classes. Those shorter than 15 cm (6 inches) tended to have somewhat higher stresses than larger seedlings (fig. 2).

On July 3, after several showers had fallen and the soil was near field capacity, stresses in Douglas-fir as small as 7.6 cm (3 inches) were unrelated to height.

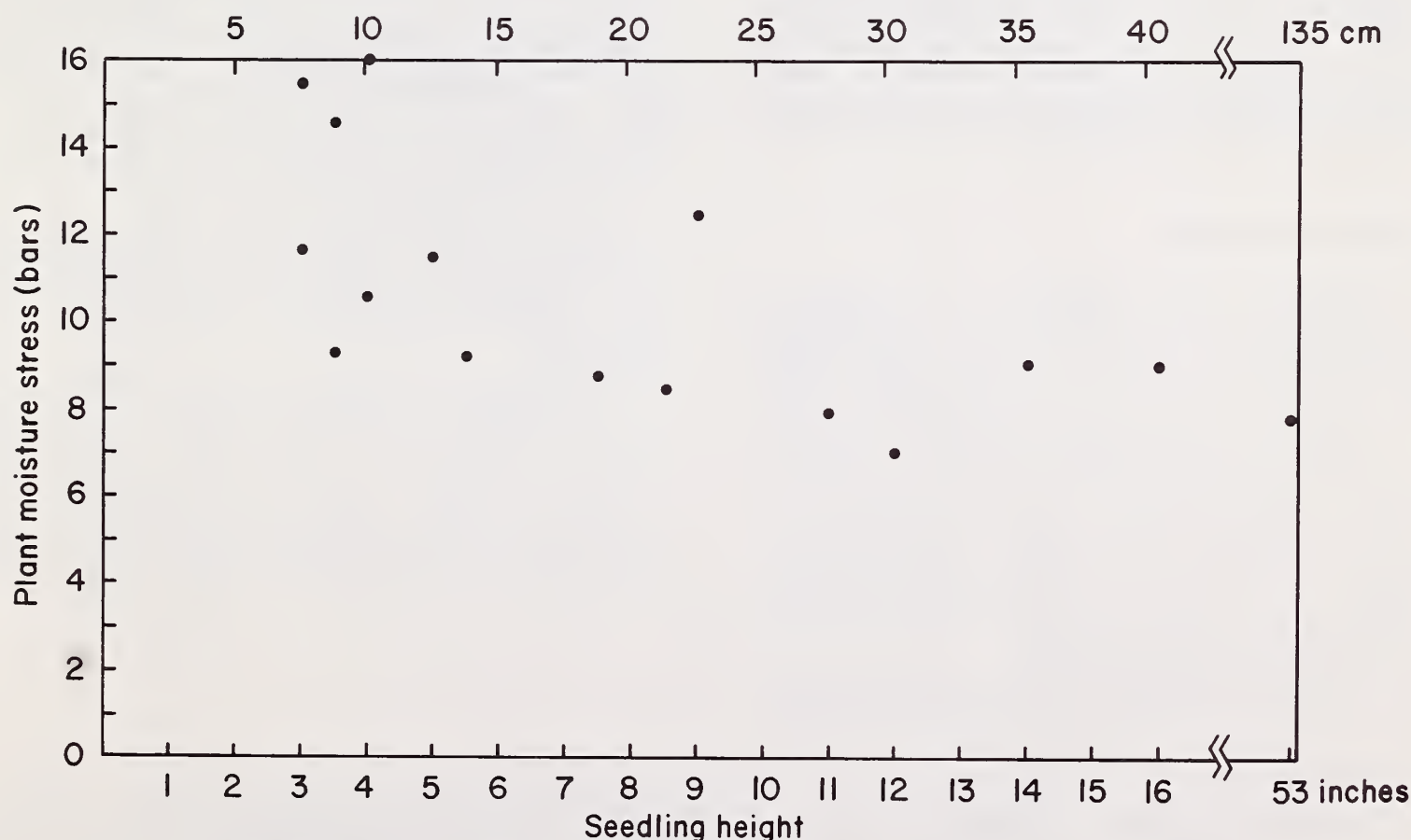


Figure 2.—Relation of plant moisture stress to corkbark fir seedling height, June 17.

Effects of Variability on Sampling

In mid-June stresses were measured in three twigs on each of five large Engelmann spruce seedlings growing in partial shade, and seven ponderosa pines (*Pinus ponderosa*) growing in a somewhat grassy clearcutting. In each sample the variation between trees was very significantly greater than the variation within trees. Therefore it should be more efficient to measure single samples from 10 trees than to measure two samples from each of five trees.

According to Waring and Cleary (1967), stress variability is greatest when stresses are highest. This should be at midday, late in the dry season, in small seedlings. A few days before the first shower of the rainy season, midday stresses were measured in 29 Douglas-fir seedlings growing in an old roadway. Almost all were between 11.4 and 19 cm tall (4.5 - 7.5 inches). Stresses averaged 13.1 bars, with a standard deviation of 1.8. A sample of five would have estimated the true mean with a standard error of 0.8 bar.

Sunny vs Shady Side

In mid-June, midday stresses were measured on three sunny-side twigs and three shady-side twigs on each of five bushy Engelmann spruces. The average of sunny-side stresses was 13.9 bars and of shady-side stresses, 12.5 bars. Even with a sample of only five trees the difference was statistically significant.

Species Differences

Stresses were compared in Douglas-fir, Engelmann spruce, and corkbark fir growing intermingled in a small opening. Sample trees, six of each species, were all dominants within the opening and between 104 and 178 cm tall.

Average dawn recovery levels of corkbark fir and Engelmann spruce were the same—5.7 bars. Their difference from Douglas-fir, with an average stress of 6.2 bars, was highly significant ($P < 0.001$). The difference, however, could easily result from species-related biases in the pressure bomb method.

When the same trees were used for a mid-day comparison, their average stresses were:

Douglas-fir	12.4 bars
Engelmann spruce	11.8 bars
corkbark fir	9.4 bars

Statistically, each species differed from the next in rank with $P < 0.001$. The difference between Douglas-fir and Engelmann spruce is small enough that perhaps their midday readings could be used interchangeably in comparing habitats, but midday readings of corkbark fir clearly cannot be used as equivalent to the others.

Diurnal Stress Changes

On two different days, stresses were measured from well before sunup until they returned to dawn levels at the end of the day.

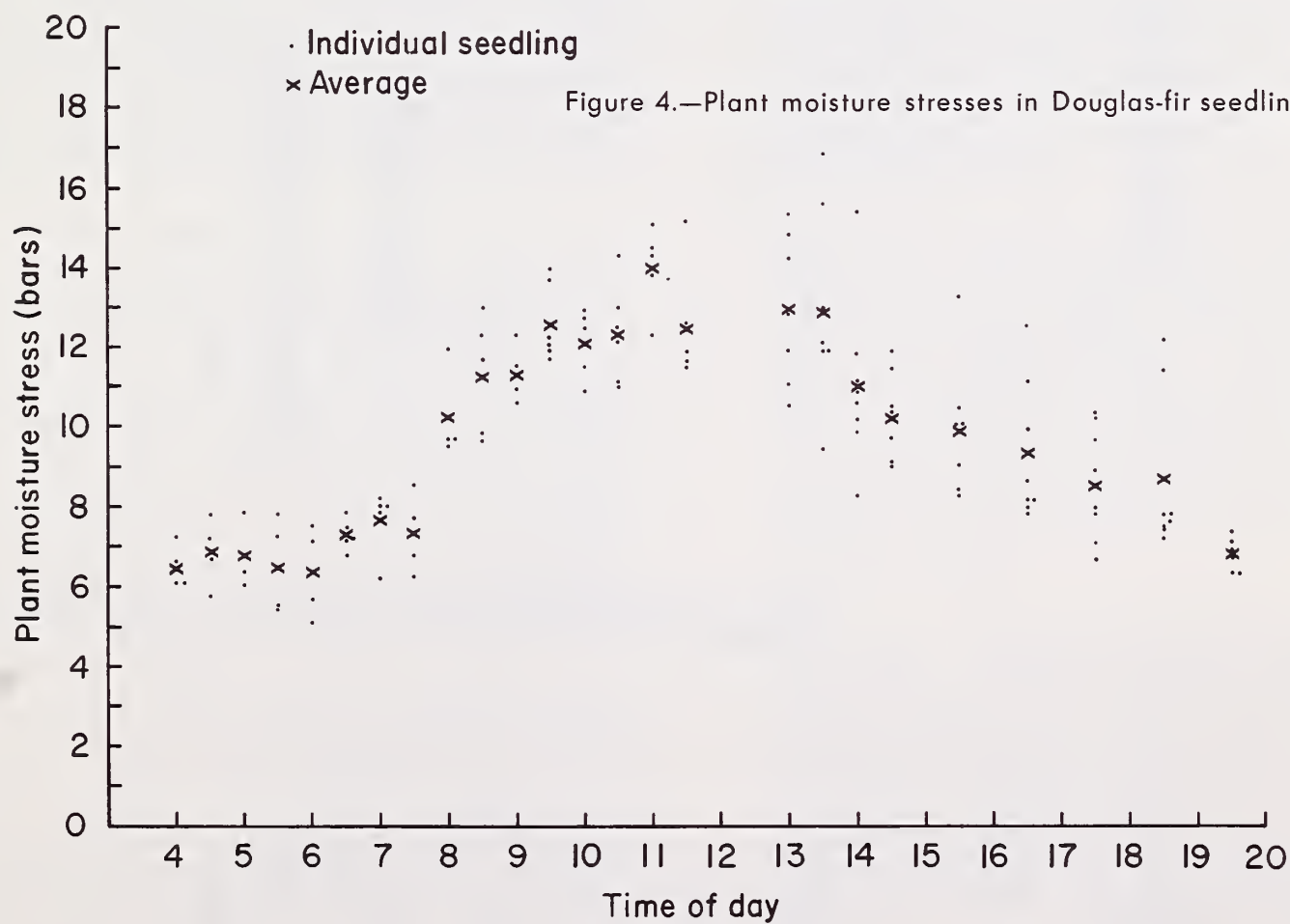
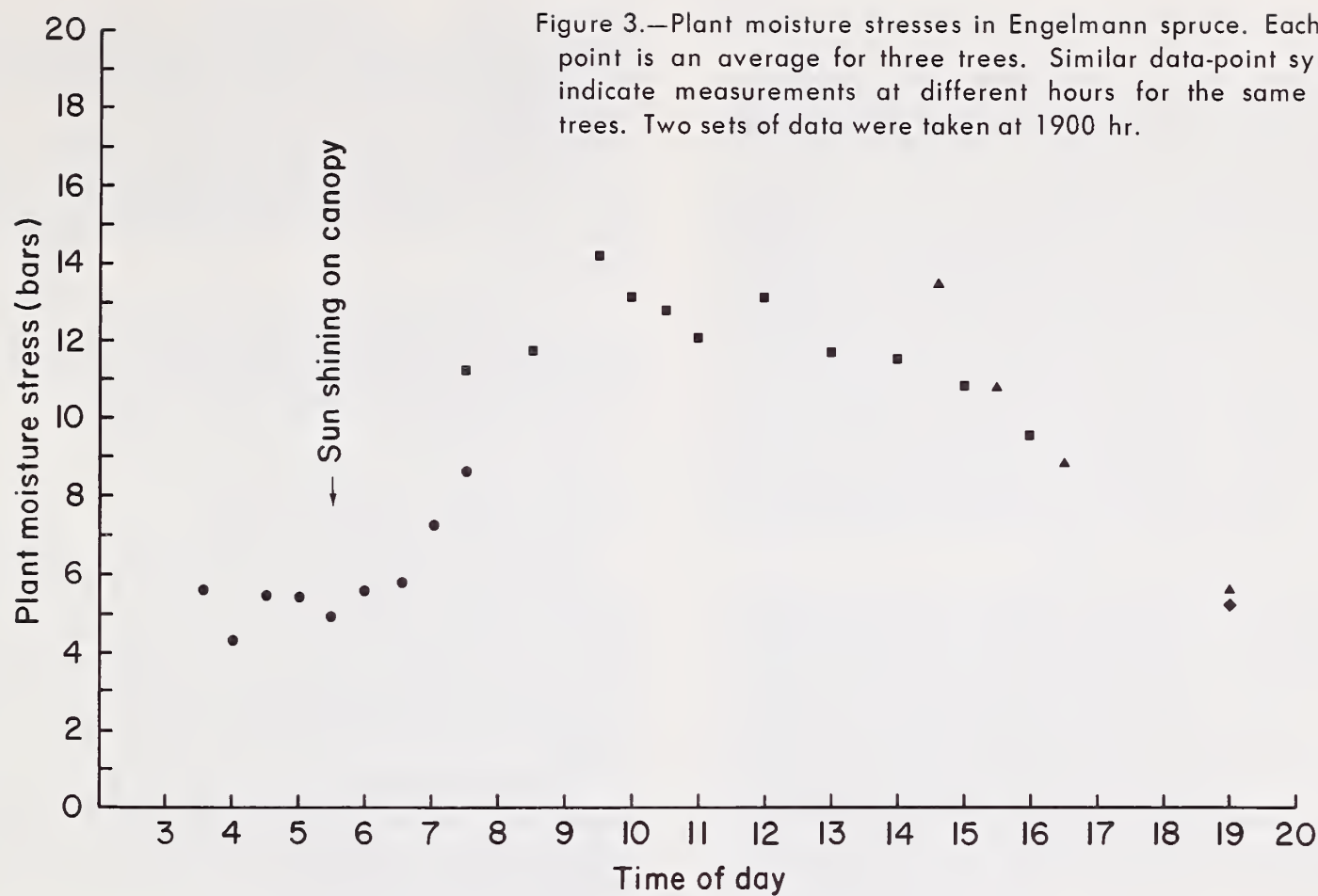
On May 23, stresses were measured on Engelmann spruce 1.5 to 2 m tall, growing in a partially cut stand. These larger trees were selected because they could be sampled repeatedly to reduce the effect of between-trees variation. Sampling of a given tree was abandoned before about 5 percent of the twigs had been removed, well below the level of removal expected to affect stress.² The results are shown in figure 3.

On June 18, stresses were measured in Douglas-fir seedlings less than 30 cm tall, mostly 10-20 cm (4-8 inches). They were growing in an abandoned roadway, and were shaded from the sides most of the day. Because an entire seedling was used for most measurements, the values for each hour (fig. 4) are from a different group of seedlings. Until after 1100 the only direct sunlight received by any of the seedlings was an occasional sunfleck. At 1200 and 1230 all seedlings were in direct sunlight, and no stresses were measured.

The graphs for the 2 days are quite similar. Seedlings on the second date did not rehydrate so completely at night, but the species difference already demonstrated probably accounts for that.

It appears that, even when working with small seedlings, recovery levels in the shade can be determined in the White Mountains at least as early as 2000 and at least as late in the morning as 0600. Daily highs can be measured from 0930 until noon, and under unspecified circumstances until 1300 or 1330.

²Campbell, C. J., and C. P. Pase. *Changes in moisture stress of birchleaf mountainmahogany after partial crown removal.* (Manuscript in preparation at Rocky Mt. Forest and Range Exp. Stn.)



Changes During the Season

Midday stresses in ponderosa pine seedlings were measured periodically on a nearly level clearcutting with a very gravelly loam soil. Grass was sparse and short.

All the stresses shown (fig. 5), except those on May 26, are from seedlings that had been in the sun for several hours. The stress differences on different days are highly significant, statistically, but do not form an ascending series such as Cleary (1969) demonstrated for southwestern Oregon during the much longer, warmer dry season there. Most of the seedlings in this experiment were 5 or 6 years old, and ranged from 18 to 92 cm tall (7-36 inches). Smaller seedlings in heavy grass might have shown an increasing trend.

The day-to-day differences in plant moisture stress shown in figure 5 seem due to weather differences. On May 21, when the highest stresses were measured, the wind was stronger than at any subsequent measurement in this experiment, and the relative humidity was 33 percent. Five dry days later, measurements taken under heavy clouds were the lowest in the series; the air was still and the relative humidity 60 percent. Later that day a heavy

shower fell. Two days later, with the sun shining, stresses were significantly higher again, although the upper soil had been thoroughly rewetted.

At the end of July, with the entire soil profile near or above field capacity, stresses late on a sunny morning were only a little lower than on similar sunny days during the dry season.

A series of dawn stress measurements in the clearcutting showed that nighttime recovery levels did not change during the dry season. Averages ranged from 7.2 to 7.6 bars.

Effects of Grass and Elevation

Effects of grass and elevation were not established. No area of heavy grass was found with enough seedlings for a comparison. An area of moderate grass cover was compared with an area of sparse grass 7 km away. Stress differences in 6-year-old ponderosa pine were trivial.

Stress differences in 6-year-old ponderosa pine also were trivial when two otherwise similar areas differing in elevation by 460 m (1500 feet) were compared.

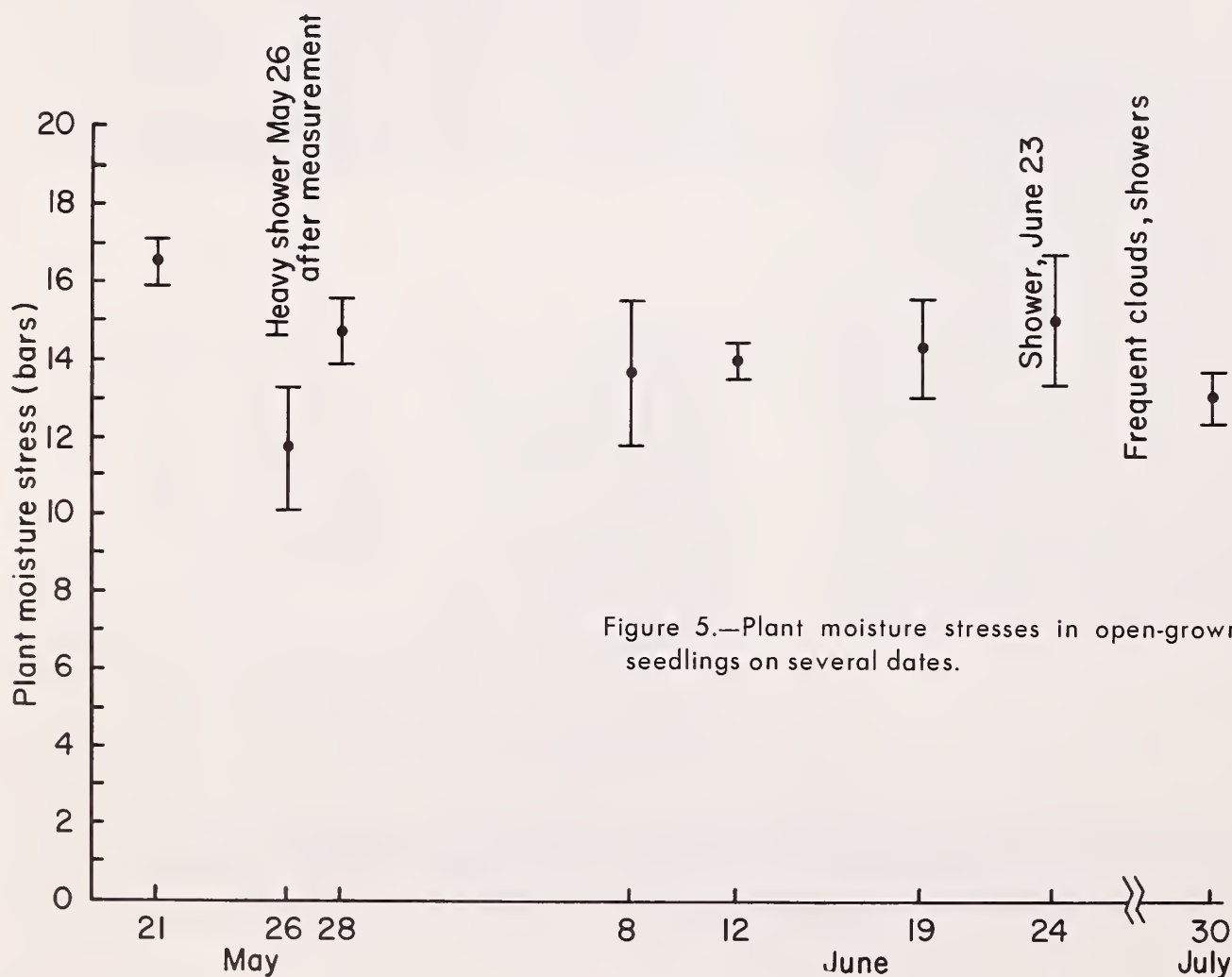


Figure 5.—Plant moisture stresses in open-grown ponderosa pine seedlings on several dates.

Discussion

Several factors might tend to cause higher plant moisture stresses in other mixed conifer areas in the Southwest. These include coarser soils, lighter snowpacks, lower elevations, higher temperatures, and delayed and less frequent summer rains.

Survival

The rather low plant moisture stresses measured indicate that spring dry-season effects are not so severe as commonly thought. We have no measurements from those conditions most likely to be critical, however, nor the seedling sizes most likely to be seriously affected. Few seedlings were found in grassy clearcuttings, and most clearcuttings in the White Mountains are grassy. Seedlings less than about 6 cm (2.5 inches) tall (typical 3-yr-olds) could not be used in our bomb.

It was encouraging to find no severe moisture stresses in seedlings of planting-stock size. Soil moisture data from the same locale indicate that, at soil depths accessible to planting stock, moisture supplies normally are suitable for survival (Embry 1971). Known exceptions are soils with heavy grass cover on both level ground and southerly slopes, where the permanent wilting point was reached or approached from the surface to the greatest depth sampled—40 cm (16 inches). Newly transplanted seedlings may be handicapped, however; because of lifting, handling, and so forth, their root systems may not extract water with normal efficiency during the first growing season.

Function and Growth

For a period of 5 to 8 hr, beginning about 0800, moisture stresses measured in stems were above 11 bars, even in cloudy weather. Brix (1962) found that loblolly pine seedlings stopped photosynthesizing when stresses in **needles** reached 11 bars. Respiration was also reduced. This suggests that photosynthesis in mixed conifer seedlings, too, may be zero during a considerable part of the day. According to Ritchie and Hinckley (1971) however, moisture stresses measured in needles of some coniferous species are often several bars lower than those measured in stems.

No data were obtained relating seedling growth to plant moisture stresses in mixed conifers. Where soil moisture stresses are high, however, the literature suggests that seedling growth is restricted. Growth reduction exposes seedlings for a longer time to serious injury or death from rodents, soil insects, cattle, deer, and elk.

Habitat Classification

There seem to be two main approaches available for classifying regeneration habitats. One is to develop a continuum model of regeneration habitats and classify by subdividing the model. Plant moisture stress might be a useful tool in modeling the moisture regime. The other approach is to classify vegetation site types or physiographic site types directly. Here, plant moisture stress might be used to test and to refine or modify the types.

Although this study neither established nor disproved the usefulness of plant moisture stress for classifying regeneration habitats in the southwestern mixed conifers, it did indicate the following limitations and directions:

1. Except for the true firs (*Abies*) and some southwestern white pine (*Pinus strobiformis*), the seeds of almost all southwestern mixed conifers germinate after the summer rains begin. Those summer germinants face their first spring dry season with root penetration averaging as little as 6 cm and as much as 20 cm (2.4-8 inches), depending on the species. Limited study indicates they do not penetrate much deeper until the third or fourth growing season (Jones 1971).

Consequently, in classifying moisture regimes for natural regeneration, we need to know the stresses experienced by seedlings during their first two or three dry seasons, seedlings mostly less than 5 cm (2 inches) tall. Larger seedlings cannot be used to characterize the stresses in such small seedlings.

Even the smallest seedlings used in this study recovered well at night, so dawn stresses seem less promising than midday stresses for use in the White Mountains. And measurements of midday stresses in very small seedlings will have to be somewhat more sensitive to habitat differences than stress measurements in the seedling sizes used here. Otherwise habitat differences will be obscured by other factors.

2. If several locations are to be measured the same day to minimize effects of day-to-day weather differences, it will be desirable to have two or more pressure bombs operating at different locations. Otherwise, travel time, combined with the number of seedlings needed to characterize the site adequately and the time required per seedling, would spread the readings over too much of the day.

3. The frequent shortage or absence of suitable seedlings where they are wanted makes artificial seeding seem necessary for test stock. That should also give maximum uniformity. Species differences need to be considered, and artificial seeding permits use of selected species.
4. The available mixed conifer clearcuttings do not sample the mixed conifer habitats at all adequately, so sampling in forest stands seems necessary.
5. At lower mixed conifer elevations, Engelmann spruce and corkbark fir are usually absent, and ponderosa pine seedlings do poorly under the canopy. White fir and corkbark fir germinate in the spring, and many die. White pine, ponderosa pine, and the surviving white firs root somewhat more deeply the first year than do Douglas-fir, the spruces, and corkbark fir. Douglas-fir is the most widespread of the mixed conifers, and in many parts of the Southwest the most abundant. These considerations suggest Douglas-fir as best suited for habitat classification work.

Primary Management Significance

This study has a major management implication, especially when considered in conjunction with (1) Embry's (1971) soil moisture study, (2) what is known of seedling rooting depths (Jones 1971), and (3) what has been learned from studies in progress. In loamy soils in the White Mountains, and presumably in other areas with similar moisture regimes, drought is normally not a major factor in seedling survival beyond age two, and in pines, not even in the first dry season, except where there is grass cover. Moderate grass cover does not cause serious moisture stresses in seedlings as well rooted as 6-yr-old ponderosa pine.

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